INTERNATIONAL JOURNAL OF MECHANICS
DOI: 10.46300/9104.2020.14.20 Volume 14, 2020

V-belts and their performance resulting from their inner hybrid structure

Zuzana Murčinková, Svetlana Radchenko, Tibor Krenický, Jozef Maščeník,
Technical University of Košice, Faculty of Manufacturing Technologies with seat in Prešov
Bayerova 1, 080 01 Prešov
Slovak Republic

Received: May 14, 2020. Revised: June 24, 2020. 2nd Revised: August 24, 2020.
Accepted: August 25, 2020. Published: August 26, 2020.

Abstract—Paper provides a study and comparison of narrow and classical cross-sections of five V-belts with different inner structure, material composition and shape. The performance is evaluated by non-contact monitoring of transversal vibration velocity together with belt temperature caused by friction and vibrations at various operational states when changing the loading, revolutions of driver pulley and tensioning force. Moreover, the vibration regimes are observed. The study presents whether concave sides, adhesion layer, higher compression core, transverse reinforcing fibers, notches, wrap of profile, naked belt sides cause the different performance.

Keywords—classical and narrow profile, cogged belt, performance, operational state, vibration, belt temperature.

I. INTRODUCTION

The belt is one component of power transmission process. It transmits a power and speed from prime mover (electric motor, engine) to driven components.

The power is transmitted by friction between the pulley and belt. In general, the belt drivers are of high efficiency and minimal maintenance and quick replacement, with relatively quiet operation. Naturally, the power is not transmitted with efficiency 100 %. The amount of transmitted power of belt drive depends mainly on the velocity of the belt, the pulley-belt slip, the arc of pulley-belt contact and proper pre-tension of belt. Moreover, the energy loss is caused by static and dynamic unbalance, misalignment etc. The more energy efficient transmission is still required. Modern V and multi-ribbed belts used in automotive applications as well as in conveyor belts are built of several functional layers [1]. The modern belts are belts with sophisticated shape and structure that creates the composite structure based on mainly elastomer materials and cords preferably made of steel. The configuration of composite structure is layered as the all cross-section can be divided into tension and compression parts and thus the requirements are different. Mainly compression part of V-belts cross-section can be made of wear protective and vibration absorption layers of various materials and compositions.

The materials of belts are preferably elastomers of viscoelastic behaviour characterized by hysteresis effects which are appropriate for damping of the mentioned belt vibrations occurring between driver and follower machines. On the other hand, the hysteresis is source of power loss due to bending, tension, shear, flank and radial compression phenomena that are cyclically repeated when belt is running. Bending deformation occurs when belt running on and off pulleys. Naturally, the tension occurs in belt as tensioning force is between both pulleys. Between individual layers of belt, the shear appears. The belt is compressed on the sides of pulley groove and flank compression occurs. Running the belt across the pulley, the normal (radial) force cause the radial compression of belt.

The demand of higher productivity invokes need of high-speed performance of machines and thus invokes demands on the research to ensure reliable and effective operation and production process. The researchers are focused on specific elastomeric materials and bring the different internal belt structures and material compositions to improve power and friction transmission, wear, heat and cold resistance and durability. About thirty and more years ago, the research was focused mainly on development the elastomeric material of high and low temperature resistant properties [2, 3]. In present and about fifteen years ago, research has been focusing on internal structure of V and flat belts along with material composition. The various hybrid composite belt structures were developed containing reinforcing chopped carbon fibres of various dimensions preferably in cushion section, load-carrying and/or tension sections [4], cords across belt width [5], short fibres such as cotton, polyamide, vinylon, rayon, aramid, etc., with the lengths of the fibres aligned generally widthwise of the belt [6], three rubber layers different by shape and composition with randomly distributed short fibres in tension section and with short fibres implemented on all of the rib surfaces as a solid lubricant [7]. There are other belt embodiments with elastomeric compositions of power transmissions belt containing reinforcement of short fibres of different materials even natural fibres as kenaf fibre [8] and sophisticated orientation and location of short fibres [9, 10], reinforcing fabrics [11, 12], and specific porous structure rubber at rib surfaces [13]. Some relevant studies can be found in [14-17].

Authors in [18-23] made various belt testing on belt test benches. Tests were focused on evaluation of power transmission efficiency of belts, impact of belt tensioning [18], belt roughness [19], low and time-varying velocity and transversal vibration performance [20], failure analysis based on vibrations [21]. Some of mentioned studies were performed on belt test benches of different complexity for example [18-23].

In our study, we compare behaviour of narrow a classical V-profiles with different structure to find if the differences in shape and structure resulting in different performance through the non-contact monitoring of the transversal vibrations together with measuring the belt temperature caused by belt-pulley friction and vibrations which characterized our measurement

II. EXPERIMENTAL SETUP AND INSTRUMENTATION

Measurement setup (Fig. 1) involved two scientific measuring instruments and software:

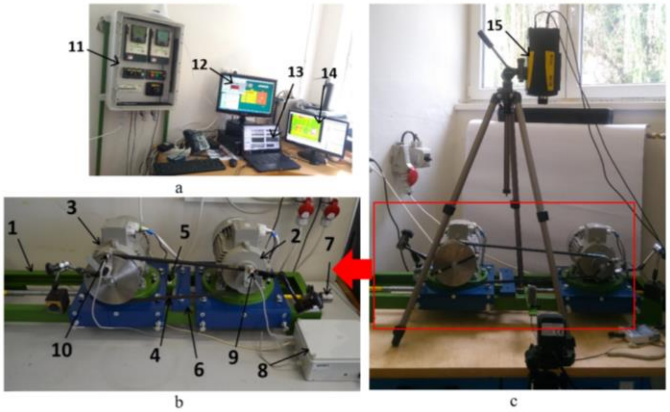


Fig. 1 Measurement components: 1 – steel frame, 2 – driver electric motor, 3 - driven motor- simulating the loading of machine, 4 - belt, 5 – force sensor, 6 - plate, 7 - tensioning screw, 8- converter, 9- sensor of actual revolutions of driver pulley, 10 - sensor of actual revolutions of driven belt pulley, 11 - control and regulate unit, 12 - Motor software (belt slip monitoring), 13 - LabVIEW software, 14 - TIM Connect software for thermo-camera TIM450 (not shown), 15 - Polytec PDV 100 vibrometer

- non-contact vibrometer Polytec PDV 100 (Fig. 1c, number 15) with analysing software LabVIEW (Fig. 1a, number 13) for measuring of belt lateral vibrations on the belt slack side,
- non-contact thermo-camera Tim 450 with software TIM Connect (Fig. 1a, number 14) for measuring belt temperature of tested belt.

Belt test bench apparatus (Fig. 1b) was made for testing the belt slip of V-belts while loading the driver. The revolutions and load was controlled by a control and regulate unit (Fig. 1a, number 11). Developed software named “Motor” (Fig. 1a, number 12) provided the information of tensioning force, actual speed of driver and driven electric motors, slip revolutions, and coefficient of elastic slip.

The belt test bench (Fig. 1b) consisted of a steel base frame 1, a pair of driver and driven electric motors 2 and 3 placed on the slides mounted on the base frame. The slides was for adjustment of tension force by the sliding the driver or driven parts along frame 1. The belt tension was possible to control by means of a tensioning screw 7 located at the bottom of the frame and force sensor 5 and plate 6. The electric motor 2 was a three-phase driver electric motor. The electric motor 3 simulated load of driven machine (fans, pumps, machine tools) The driving and driven pulleys had diameters 80 and 160 mm, respectively. The transmission of the rotary movement between the pulleys located on the shafts of the electric motors was provided by a V-belt.

The belt driver bench allows testing of various belts by simply replacing the pulleys on the electro-motor shafts. An important factor influencing the correct performance of measurement and testing of belt drives is the correct belt tension. For this purpose, the belt drive was equipped with a tensometer sensor EMSYST EMS50 which was located between the plate 6 and sliding bed of steel base frame 1.

A. Description of tested V-belts

The V-belts were all of wedge type A, belt size 13 and length (L_d 1480 – 1485). The cross-section of each V-belt is trapezium shape. The cords as tension member with a high tensile strength provides and carries up to 95 % of the torque loading during the operation of the V-belt drive system. The rubber layers ensure frictional and absorbing shock properties and transmits the torque between the pulley and cords. The textile top cover (wrap) protect the V-belt during operation. The strength of V-belts is achieved by twisted load-carrying tensile cords. Table 1 provides the basic characteristics of tested belts.

More detailed description of belts in Table 1 is following: Belts 1 – 3 were wrapped by rubberized fabric outer material. The longitudinal profile of belts 4 and 5 involved notches, named cogged or raw edge cogged with no fabric cover on the sides. Belts 2, 4 and 5 were of narrow wedge. It means that tensile and load-carrying part of belt were the same as classical wedge, but compression part was larger. Moreover, belts 4 and 5 had reinforcing fibres oriented in direction of profile width.

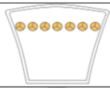
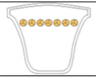
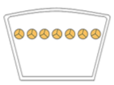
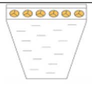
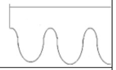
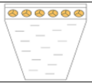
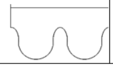
Moreover, the structure and material composition of :

- belts 1, 2, 3: cover fabric; over cord cover from polychloroprene (cushion part); tensile cords made from polyester fibres with adhesion cover; compression core from polychloroprene,

- belts 4: top fabric (only on the top surface); over cord cover from polychloroprene (cushion part); tensile cords made from polyester fibres with adhesion cover; compression core from polychloroprene with fibres in width direction,
- belt 5: double top fabric; adhesion layer with transverse glass fibres; polyester tensile cords; adhesion layer with transverse glass fibres; compression core from polychloroprene with fibres in width direction.

We can recognize the internal structure of the belts (cords in rubber body, layers of fabric, reinforcing fibres) as hybrid structure since it contains different materials and different shapes and textures. Belts 1-3 did not contain transverse reinforcing fibres, but they were covered with cover fabric. The opposite was true for belts 4 and 5.

Table 1. Tested V-belts

V-belt		Wedge/Catalog profile dimension [mm]	Weight [kg]	Profile	Longitudinal profile	View
1	Hi-Power A58 13x1475Li	classical wrap/13x8	0.190		-	
2	Super HC SPA 1482	narrow wrap/13x10	0.204		-	
3	Delta classic A57 13x1450Li/ 1480Ld	classical wrap/13x8	0.164		-	
4	Super HC MN SPA 1482 MN	narrow cogged/13x10	0.154			
5	Quad-Power 4 XPA 1482	narrow cogged/13x10	0.141			

Belts 1 and 3 of classical profiles had the concave sides shaping into groove when tensioning the belt. The upper surface was rounded. The cover fabric was resistant to oils and temperature and protects the core.

Belt 2 with narrow profile, cover fabric, concave sides, rounded top and rounded edges helped to obtain uniform tensile load and uniform contact with pulley groove.

Belt 4 was for higher power transmission, higher gear ratios or smaller pulley diameters.

Belt 5 was high-power V-belt made of quality polychloroprene mixture resistant to aggressive environment, aging, UV radiation, temperature, abrasion and wear. Fibres in width direction (also belt 4) in compression section ensured the longitudinal belt elasticity and transverse stability of the belt. An adhesion layer with transverse glass fibres was important connecting layer between cords and compression core. Cords were highly elastic and the side walls fit exactly and provided an uniform transmission of force.

B. *Loading – operational states*

During testing, as the operating conditions we considered the sequential measurements in different operational modes in following order: load of driven electric motor was 0% and rotational speeds gradually 600, 1200, 2000 and 3000 rpm, then 40% and gradually 600, 1200, 2000 and 3000 rpm. All operational modes for tensioning force 400 N and then for 700N.

III. RESULTS

A. *Operational states and vibrations*

Fig. 2 shows vibration behaviour for minimal (load 0%, tensioning force 400N – dashed lines) and maximal (load 40% and tensioning force 700N – continuous lines) operational states. The classical belts with wrap, i.e. belts 1 and 3, behaved very stably. Increase of revolutions almost did not change the vibration velocity in range of 1200 – 3000 rpm. Narrow and wrap profile (belt 2) behaved with largest changes in vibration velocity. The belts with narrow, unwrapped profile, but cogged have also large changes in vibration velocity (mainly belt 4), however, comparing the their behaviour of minimum and maximum operational states, the behaviour is very similar.

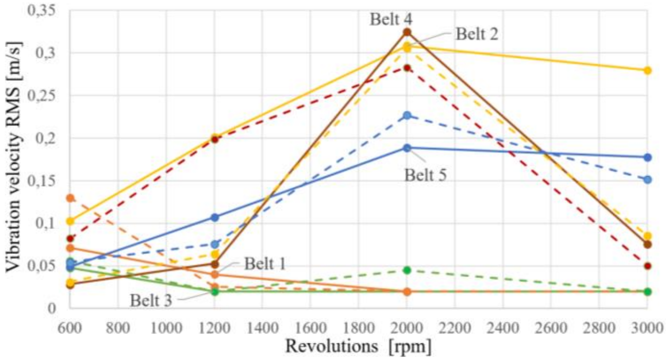


Fig. 2 Velocity of transversal vibration RMS; dashed lines load 0%, tensioning force 400N; continuous lines load 40% and tensioning force 700N

B. *Vibration regimes*

The velocity of transversal vibration in Fig. 2 is presented by RMS (root mean square) vibrational velocity values as the belt vibrate in some vibration regimes presented in time period 1s in Figs. 3 and 4.

The belt behaves as string when running and depending on natural frequency, speed, belt temperature, assembling the belt drive (static and dynamic unbalance, misalignment etc.) etc. Thus the belt takes the different natural modes in different operational states. It is visible in Fig. 3. The belt 1 at 600 rpm has larger vibrations. At 1200 rpm, when running without load the vibrations are low, but increased load (40%) make the belt more vibrating. At 2000 and 3000 rpm the vibrations are low and stable. The mentioned is for the same tensioning force.

In Fig. 4, the other typical vibration regimes are presented.

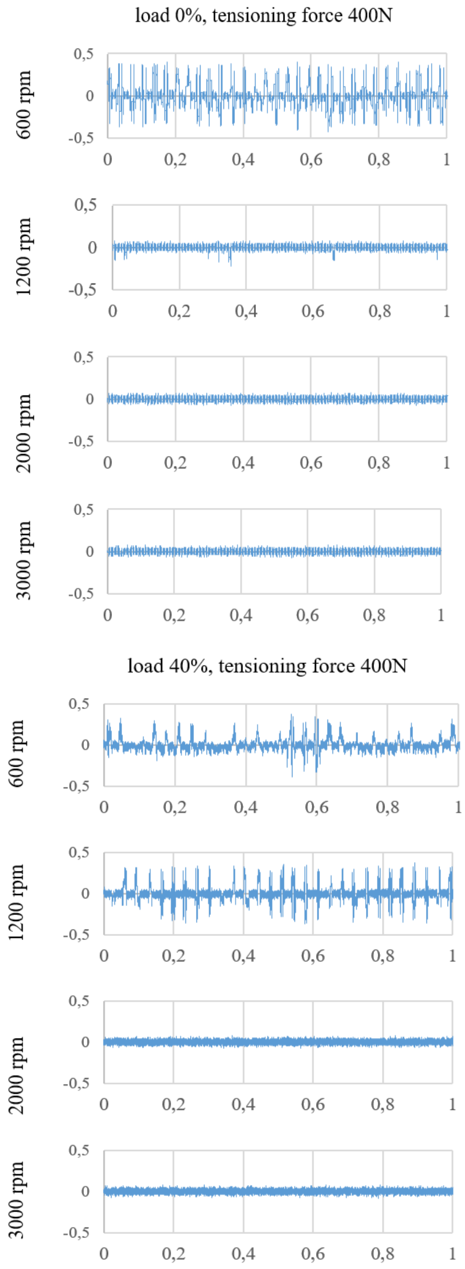
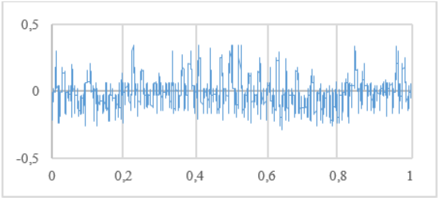
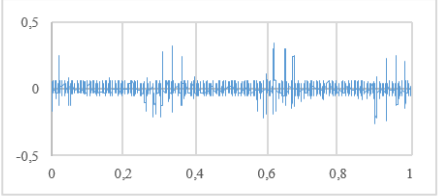


Fig. 3 Belt 1. Velocity of transversal vibrations – time record (1s)



40%, 700N, 600rpm, belt 1



0% 700N, 1200rpm, belt 1

Fig. 4 Other specific vibration regimes

The most suitable performance is that of belt 3 (classical and wrapped, based on evaluation just RMS of transversal vibrations. However, we involved in measurement even belt temperature behaviour.

C. 3.3 Study of belt temperature

Temperature caused by friction between belt and pulley and vibrations is important parameter to be evaluated. Temperature plot in Fig. 5 is obtained by measuring temperature when changing step by step operational states: load 0%, tensioning force 400N, 600, 1200, 2000, 3000rpm; load 40%, tensioning force 400N, 600, 1200, 2000, 3000rpm; 75% 600 rpm; 100% - 600 rpm; load 0%, tensioning force 700N, 600, 1200, 2000, 3000rpm; load 40%, tensioning force 700N, 600, 1200, 2000, 3000rpm.

Curves for belts 1, 2 and 3 have peaks. Peaks corresponds mainly with the largest revolutions. However, in case of cogged belts 4 and 5, there are no peaks, the temperature is stable without reaction on operational states conditions in testing range and period (about 80 minutes).

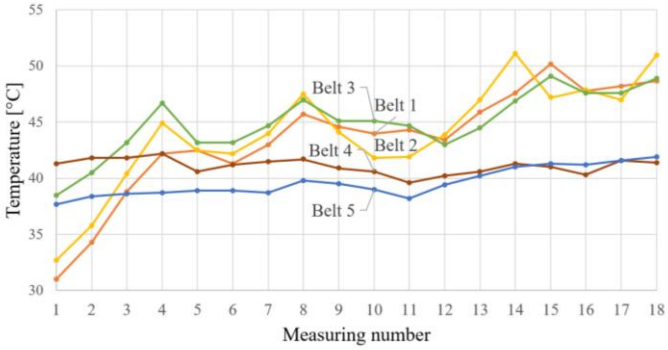
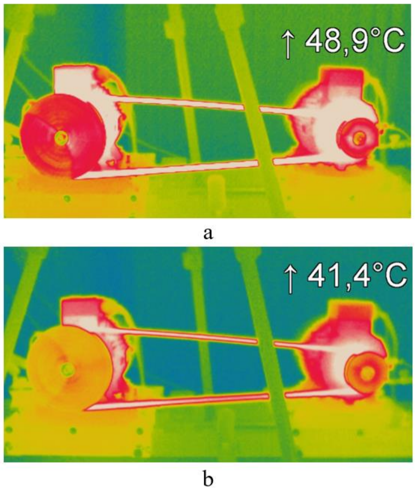


Fig. 5 Temperature

Belt 3 have the best results regarding lowest values of velocity of transversal vibrations, however the average temperature is the largest. Fig. 6a shows its temperature distribution at the end of measurement. At the same time Fig. 6b shows the same for belt 4 (narrow and cogged) with the best results ranking all parameters (velocity vibrations, temperature change, average temperature).



a

b

Fig. 6 Temperature for belts 3 and 4 at the end of measurement

IV. CONCLUSION AND DISCUSSION

The different belts regarding structure and shape were chosen for testing. One can expect the very similar behaviour as all belts were of same belt size 13. However, not large differences in profile cross-section and longitudinal profile (un-cogged, cogged) cause various responses in vibration and temperature.

Same inner structure and shape of belts 1 and 3 provides same performance. Similar inner structure of belts 4 and 5 provides similar performance that is different from performance of belts 1 and 3 with different inner structure and shape. The individual performance is for belt 2 that has individual structure and shape differ from all other belts. However, all belts are of same size 13.

Evaluating chosen parameters (Table 3), i.e. overall average RMS velocity of transversal vibration, temperature change and average temperature, the best ranking is for belt 4.

Table 2. Evaluation

Belt	1	2	3	4	5
Overall average vibration velocity RMS (mm/s)	0.0588	0.1380	0.0416	0.1278	0.0529
Vibration velocity RMS ranking:	2nd	5th	1st	3rd	4th
Temperature change Δ*t* (°C)	16	13	10.2	0.3	3.8
Δ*t* ranking	5th	4th	3rd	1st	2nd
Average temperature (°C)	44.3363	44.4952	45.8045	41.0800	39.8100
Temperature ranking:	3rd	4th	5th	2nd	1st
Points (line 3+line 5+ line 7)	10	13	9	6	7
Overall rank:	4th	5th	3rd	1st	2nd

The inner hybrid structure of belts contributes the direction towards the more energy efficient transmission of belt drivers.

We can confirm regarding results the properties presented by producer that belt 4 and 5 are intended for the highest power transmission and provided the best performance. We can confirm that the inner hybrid structure. i.e. outer layers of fabric, reinforcing fibres, adhesion additional layer and belt profile shape, notches, wrap, concave belt sides have significant impact on vibration and belt temperature performance of V belts.

ACKNOWLEDGMENT

The authors would like to thank the Agency of Ministry of Education, Science, Research and Sport of the Slovak Republic for supporting this research: grant VEGA 1/0910/17.

References

[1] A. Tonoli, N. Amati, E. Zenerino, “Dynamic modeling of belt drive systems: effects of the shear deformations,” Journal of Vibration and Acoustic, 2006, pp. 555-567.

[2] P.M. Patterson, Gates Rubber Co, “High temperature polyurethane belt,” U.S. Patent 5,112,282, 1992.

[3] S.L. Ciemniecki, R.A. Rorrer, H.D. Visser, H.D., Gates Corp, “High temperature flexible thermoplastic composites for endless belt driving surfaces,” U.S. Patent 6,296,588, 2001.

[4] M.J.W. Gregg, T.G. Burrowes, Goodyear Tire and Rubber Co, “Power transmission belt containing chopped carbon fibers,” U.S. Patent 6,918,849, 2005.

[5] P.S. Knutson, Gates Corp, "Power transmission belt and method," U.S. Patent No. 6,945,891, 2005.

[6] Y. Hineno, T. Nishiyama, T. Takada, H. Takechi, K. Takeda, Mitsuboshi Belting Ltd, “Rubber composition and power transmission belt incorporating the rubber composition,” U.S. Patent 7,485,060, 2009.

[7] M. Mitsutomi, Y. Hineno, S. Shimoo, Mitsuboshi Belting Ltd, “Power transmission belt,” U.S. Patent 9,273,756, 2016.

[8] Y. Feng, Gates Corp, “Kenaf reinforced rubber for power transmission belts,” U.S. Patent 9,255,201, 2016.

[9] S. Uchigashima, M. Yamada, Y. Harada, A. Terasaki, K. Shimamura, Honda Motor Co Ltd and Gates Unitta Asia Co, “Toothed belt,” U.S. Patent 9,353,827, 2016.

[10] Y. Takami, F. Ise, H. Kawahara, H. Enokizono, T. Sawairi, Asahi Kasei Corp, “Short rubber reinforcement fiber, rubber composition containing said short fiber, and power transmission belt,” U.S. Patent 10,215,257, 2019.

[11] T. Yamamoto, T. Nozaki, Nitta Corp, “Flat belt,” U.S. Patent Application 11/393,870, 2006.

[12] H. Okamura, Y. Konishi, M. Ono, N. Nakai, N. Kai, Nitta Corp, “Endless flat belt and method for manufacturing the same,” U.S. Patent 10,570,990, 2020.

[13] T. Okubo, K. Hara, Bando Chemical Industries Ltd, “V-ribbed belt,” U.S. Patent 10,274,045. 2019.

[14] A. Skrobak, M. Reznicek, M. Ovsik, V. Janostik, “The Influence of Injection Molding on Tensile and Tear Properties of EPDM Rubber,” WSEAS Transactions on Applied and Theoretical Mechanics, vol. 13, 2018, pp. 150-156.

[15] T. Sysala, K. Stuchlik, P. Neumann, “An Alternative to the Band Saw Wheel Wear Measurement, WSEAS Transactions on Systems and Control,” vol. 13, 2018, pp. 473-480.

[16] V. Kompiš, Z. Murčinková, Z., M. Očkay, “Temperature fields in short fibre composites,” In Computational modelling and advanced simulations Springer, Dordrecht. 2011, pp. 99-116.

[17] Z. Murčinková, T. Krenický, “Applications utilizing the damping of composite microstructures for mechanisms of production machines and manipulator devices,” 13th International Multidisciplinary Scientific Geoconference and EXPO, SGEM 2013, Albena; Bulgaria; 16 June 2013 through 22 June 2013 pp. 23-30.

[18] S. Dereyne, E. Algoet, P. Defreyne, Stockman, K., “Construction of an energy efficiency measuring test bench for belt drives,” In Energy Efficiency of Motor Driven Systems, EEMODS-2013, 2013.

[19] B. Stojanovic, S. Velickovic, J. Blagojevic, J., D. Catic, “Statistical analysis of roughness timing belt in operation using full factorial methods,” Journal of the Balkan Tribological Association, vol.21(3), 2015, pp. 514-524.

[20] G. Suweken, W.T. Van Horssen, “On the weakly nonlinear, transversal vibrations of a conveyor belt with a low and time-varying velocity,” Nonlinear Dynamics, 31(2), 2003, pp. 197-223.
[21] R. Grega, J. Krajňák, L. Žuľová, G. Fedorko, G., V. Molnár, V., “Failure analysis of driveshaft of truck body caused by vibrations,” Engineering Failure Analysis, vol. 79, 2017, pp. 208-215.
[22] M.O. Lacerte, G. Pouliot, J.S. Plante, P. Micheau, “Design and experimental demonstration of a seamless automated manual transmission using an eddy current torque bypass clutch for electric and hybrid vehicles,” SAE International Journal of Alternative Powertrains, vol. 5(1), 2016, pp. 13-22.
[23] F. Tan, D. Xuan, Y. Zhang, Z. Shi, R. Chen, R., G. Xu, “Double-Steady-State Test Bench of Reliability Performance of Shaft Tip Earthing Device in High-Speed Railway Vehicle,” In 2019 4th International Conference on Control and Robotics Engineering (ICCRE), April 2019, pp. 27-30.

Zuzana Murčinková is an associate professor in the field of Production Machinery at Technical University of Košice. PhD degree is in field Applied Mechanics and Master of Science degree is in Mechanical Engineering. She focuses on the fields of applied mechanics, production machinery, manufacturing technologies, mechanics of materials, static and dynamic simulation of mechanical behavior of structures using the finite element method. These fields of research are multidisciplinary joined in the field of applications, design and testing of composite materials. She is the lead author and co-author of 13 scientific papers in Current Content journals, 1 monography in renowned foreign publishers, 3 university textbooks and more than 80 scientific papers in the Web of Science and Scopus databases and more than 145 citations in Web of Science and Scopus databases.

Svetlana Radchenko focuses mainly on fields of industrial production management and automotive production and its automation.

Tibor Krenický deals with the following activities: design and implementation of experimental devices using virtual instrumentation, multiparametric measurement of physical quantities, evaluation of diagnostic parameters, especially in the field of vibro-diagnostics. He has good experience with the creation of innovative experimental sets for measuring quantities under controlled conditions and for processing diagnostic data.

Jozef Maščenik,, his research activity was focused on the production of teeth by unconventional technologies and design of parts of machines, mechanisms and construction nodes. Recently, his research is in in the field of belt drives testing under various conditions and extreme loads.

Contribution of individual authors

This work was carried out in collaboration between all authors. Zuzana Murčinková formulated research issues and hypothesis of presented problem and designed the research. Svetlana Radchenko methodically managed and organized experiments and evaluated results. Tibor Krenický and Jozef Maščeník conducted experiments.

Creative Commons Attribution License 4.0 (Attribution 4.0 International, CC BY 4.0)